Lidar Observation of Wind Shear along Glide Path at Beijing Capital International Airport

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Abstract: The significance of wind shear to aviation lies in its effect on aircraft performance and hence its potentially adverse effect on flight safety during landing phase especially within 500m (1600 ft) at height. The lidar team in Ocean University of China (OUC) carried out the particular research of the low level wind shear along the glide path at Beijing Capital International Airport (BCIA) in 2016 by utilizing a pulse coherent Doppler lidar (PCDL). On account of the high spatial and temporal resolution, the small-scale air mass disturbances along the glide path can be captured easily. The experiment configuration, the PCDL, the observation modes, the case study of the wind shear and the statistics of wind shear intensity are proposed and experimentally demonstrated. The reliability of wind shear identification algorithms has been proved by wind shear reports from the crew and the terminal control office.

Keywords: Pulsed coherent Doppler lidar, low-level wind shear; headwind, civil aviation safety

1. Introduction

According to the definition of International Civil Aviation Organization (ICAO), the low-level wind shear is defined as a sharply change of the wind speed or wind direction in space within 2000 feet at height. Wind shear includes vertical and horizontal components which usually occurs near fronts or coast and near the ground surface [1]. Wind shears in the lowest few hundred meters of the atmosphere have been responsible for a number of aircraft accidents [2-3]. In the years 1975 to 2006, the USA National Transportation Safety Board (NTSB) attributed wind shear as the cause of 20 aircraft accidents, with a total of over 500 fatalities [4]. There were 51 accidents caused by turbulence encounter, which account for 19 percent of the total accidents between 2014 and 2017[5]. Effective wind shear alarm systems are needed to guarantee the safety of civil aviation.

The rate of wind shear related accidents was reduced as the awareness of pilot increasing and the deployment of all current wind shear protection systems (LLWAS, PWS (Predictive Wind-Shear System), TDWR, and WSP (Weather Systems Processor)).

Due to the variable types of low-level wind shear and its uncertainty of location and quick evolution, the required high spatial and temporal resolution of the low-level wind shear detection can only be achieved by operating a PCDL with different scanning modes. In this paper, we adopt the pulse coherent Doppler lidar (PCDL) system which has been proved to be an accurate optical sensing technique to capture the small scale characteristics of wind, turbulence, wake vortices, and so forth under non-rainy weather [6-10].

The pulsed 1550 nm fiber laser source is based on the MOPA architecture with a large core fiber and excellent beam quality ($M^2=1.2$), whose pulsed energy is 150 µJ with a pulse repetition rate of 10 kHz.
and an pulse length of 200. The Fast Fourier Transform (FFT) spectral estimates are processed with FPGA (Field Programmable Gate Array) in real time. All these design of the PCDL system make it stable, reliable and high-integrated. The detailed specifications of the PCDL system are listed in the Table 1.

Table 1 Specifications of the pulsed coherent Doppler lidar system

<table>
<thead>
<tr>
<th>Qualification</th>
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<tbody>
<tr>
<td>Radial Spatial Resolution</td>
<td>30 m</td>
<td>Wavelength</td>
<td>1.5 μm</td>
</tr>
<tr>
<td>Measurement Range*</td>
<td>60 to 4000 m</td>
<td>Pulse Energy</td>
<td>150 μJ</td>
</tr>
<tr>
<td>Scanner Positioning Accuracy</td>
<td>0.1°</td>
<td>Pulse Duration</td>
<td>200 ns</td>
</tr>
<tr>
<td>Velocity Measurement Range</td>
<td>± 37.5 m/s</td>
<td>Pulse Repetition Frequency</td>
<td>10 kHz</td>
</tr>
<tr>
<td>Resolution of Velocity</td>
<td>0.1 m/s</td>
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*Weather condition related*

PPI (Plane Position Indicator) at low elevation angles has been developed and utilized during the past low-level wind shear observation campaigns to capture the wind shear events.

Wind speed retrieved from the PPI scan data is related to the intercept angle between the laser beam pointing direction and the prevailing wind. When the scanning azimuthal angles are nearly corresponding with or nearly opposite to the prevailing wind, the LOS wind speeds are nearly equal to the real wind speed. However, when the lidar beam pointing direction is nearly perpendicular to the primary wind direction, the LOS wind speed is a project component of the wind vector. If the angle of intercept is larger than 30 degrees, the radial wind data would not be utilized to construct the headwind profiles considering the increasing underestimation of the headwind component as the across angle increases.

For the study of wind shear occurring along the glide path, the PCDL was configured at the south ending of the 36L/18R runway as Figure 1 shows. Taking the 5.2° incidence angle of aircraft landing path into consideration, a Pointing PPI scanning pattern was performed in the field wind shear observation campaign to reveal the wind that aircrafts would encounter.
2. Results

Figure 2 Glide path scanning of the 36L/18R runway at BCIA on Feb 28th, 2018.

We have captured the existence of small-scale airflow disturbances embedded in the prevailing wind with high spatial resolution by operating pointing PPI scan mode as Figure 2 shows. The red and blue colors indicate positive (away from lidar) and negative (towards lidar) movement, respectively, of the atmospheric particles along the laser beam. These airflow disturbances are generally small scale with several hundred meters at horizontal dimensions and difficulty to be captured by DBS mode. The black line in Figure 2 is the extended centerlines of the runway and the width of line is about 100 m by taking the uncertainty with the flight path of the aircraft into consideration. By checking the series of PPI scans, the airflow disturbances move along glide path with the background wind flowing over the runway corridor. They are believed to arise from disruption of the northerly airflow by the artificial buildings above the ground surface.

For illustrating the transient and sporadic nature of the low level wind shear along the glide path, we construct the headwind profiles through the pointing PPI scan as Figure 3 shows. The duration of a PPI scan over the runway corridor is about 50 s (including PPI scan and data processing and data display).

Woodfield and Woods defined a severity factor $I$ of wind shear as

$$I = \left( \frac{dV}{dt} \right) \left( \frac{\Delta V}{V_{app}} \right)^2 = \frac{1}{V_{app}} \left( \frac{\Delta V}{R^{1/3}} \right),$$

where $\Delta V/R^{1/3}$ is the rate of change of wind speed, $\Delta V$ is the total change of wind, $V_{app}$ means the normal approach speed of the aircraft (75 m/s in this study) and $R$ represents the ramp length.

The value of the severity factor $I$ is 0.08 with respect to the headwind speed reduced 22 kt within 300 m. The cubic root of severity factor is used to classify the turbulence alerts into two levels: “moderate turbulence (0.3~0.5)” and “severe turbulence (>0.5)”. The value in this study is 0.409, a moderate turbulence.

More than 12000 PPI scans have been analyzed in this study. Wind shear severity factor calculated from headwind profiles are illustrated in Figure 4.
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Figure 4 Wind shear intensity-ramp length diagram for wind shear reports over 36L corridor in the period from Jan 16 to Mar 16, 2018 based on wind shear ramps detected by the PCDL system.

The blue dots represent the severity factors with the maximum difference of headwind profiles less than 15 knots, while the maximum difference of red dots exceed the threshold adopted by the ICAO. The dotted line is the standard intensity scale (the speed difference is 15 knots) with different ramp length. Different pilots might have different practices in estimating the wind shear magnitude. Due to the sudden change of speed with shorter ramp length, the intensity scale may come to high value as the black circle marked. From the relationship statics of wind shear intensity scale and ramp length, we can find that the wind shear intensity scale is maintained at relative low level even under northwest prevailing wind at most part of time. It is unreliable to alert the wind shear event by identifying single factor (maximum difference of headwind profile or wind shear severity factor).

The method to identify the wind shear based on setting threshold value (15 knots) is more reliable to monitor the low level wind shear than wind shear intensity scale. The probably reason may be the shorter ramp length in this study. The wind shear intensity scale will exceed the threshold by calculating the Eq. 1. When it comes to longer ramp length (the headwind gradient will slows down with the same speed difference), the method based on setting threshold value may cause false alarms.

The reliability of algorithms have been proved by wind shear reports from the crew and the airport terminal control office.

3. Discussion and conclusions

The PCDL system has been proved to be an effective remoting tool to detect the low-level wind shear under dry conditions. It is possible to capture the wind shear events with different observation modes. From the field wind shear observation campaign at BCIA, we developed algorithms to identify the wind shear and turbulence. Unlike the traditional wind shear monitor system (such as TDWR, PWS, and WSP), the PCDL system is unable to cover the whole airport area due to the limited coverage. However, the PCDL system is able to capture the small-scale airflow disturbances with high spatial resolution and high data updating rate. The PCDL system perform well when it was used as a complementary system to radar coverage for the identification of the terrain induced wind shear.

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Major references


